PREDICTION OF WATER YIELD OF MOUNT BANAHAW WATERSHEDS IN QUEZON PROVINCE, PHILIPPINES USING HYDROLOGIC WATER BALANCE MODEL

Prediksi Hasil Air Daerah Aliran Sungai Pegunungan Banahaw di Propinsi Quezon, Filipina Menggunakan Model Hidrologi Keseimbangan Air

Moses T. Macalinao[1], Putu Sudira[2], Sahid Susanto[2]

ProgramStudi Mekanisasi Pertanian
Program Pascasarjana Universitas Gadjah Mada

ABSTRACT

The research site was the *Janagdong* River Watershed and the *Dumacaa* River Watershed in Quezon Province, Philippines. The hydrometeorological data such as monthly rainfall, monthly potential evapotranspiration and observed monthly streamflow of both watersheds from 1986 to 1989 and from 1998 to 1999 were used to determine the parameters of the water balance model by optimization procedure. Thereafter, the parameters were used to predict the monthly streamflow.

The value of parameters a_1=0.09; a_2=0.44; a_3=0.01; a_4=0.03; and a_5=2.00 for *Janagdong* River Watershed and the value of parameters a_1=0.01; a_2=0.37; a_3=0.20; a_4=0.03; a_5=2.10 for *Dumacaa* River Watershed was obtained. The use of the model parameters was able to predict the streamflow of the two watersheds. Results showed that there is significant correlation between predicted and observed streamflow of both watersheds at 0.01 level. The test of the difference of the means of the predicted and observed streamflow of both watersheds was found not significant at 0.05 level.

Key words: *streamflow -- optimization -- watershed*

INTRODUCTION

Mount *Banahaw* is located 130 km South of Manila. It is bounded by the towns of Lucban, Tayabas and Sariaya, Candelaria and Dolores in Quezon Province and Majayjay, Lilio and San Pablo City in Laguna Province. The huge mountain serves as the source of water for domestic use and for agricultural production in the locality aside from the rainfall

1) *Southern Luzon Polytechnic College, Lucban, Quezon, Philippines*
2) *Faculty of Agriculture Technology, Gadjah Mada University, Yogyakarta, Indonesia*

that occurs regularly. Mount *Banahaw* has 3 summits. The summit of Mount *Banahaw de Lucban* has as elevation of 1,875 meters above sea level and the other two peaks of Mount *Banahaw-Cristobal* have an elevation of 2080 meters and 2169 meters above sea level. Due to its high elevation, water flows by gravity to the surrounding communities.

The water demand for domestic use and agricultural purposes of the surrounding communities is increasing. This is due to industrialization and development of the surrounding communities and increasing population. The main activity of the metropolitan waterworks and local governments is to allocate and exploit the water resources to satisfy the demand of the consumers without taking into consideration how much is the potential available water. This can be attributed not for the lack of knowledge but due to wait and see attitude. An action will be done when there is already a problem. In water resources development activities the work can not be done overnight due to its complexity and influence of nature.

Despite of the availability of climatic data from the surrounding meteorological stations of the watershed, there is no attempt yet to develop a model to estimate the water yield of the mountain. Hence, this is a preliminary attempt.

RESEARCH METHODOLOGY

The Model and Its Parameters

The monthly water balance model developed by Van Der Beken and Byloos in 1977 (Singh, 1989) was used in this study. The time period is one month. The general equation of the models is expressed as:

$$\Delta S = N_p - V_Q - R \quad (1)$$

The different components and the relationships of factors affecting the model are the following:

Evapotranspiration. The evapotranspiration is described by equation 2 as:

$$E_a = E_p \; [1 - \exp(-a_1 S)] \quad (2)$$

Effective Precipitation. The effective precipitation in relation to actual precipitation and actual evapotranspiration is described by equation no 3.

$$N = V - E \quad (3)$$

Streamflow. The streamflow in the watershed in relation to the storage at the beginning of the month, effective precipitation and constant parameters is described by equation no. 4.

$$V_Q = a_2 S + a_3 N \quad (4)$$

Deep Percolation and Canal Loss. The deep percolation and canal loss in relation to storage at the beginning of the month and constant parameters is described by equation no. 5.

$$R = a_4 S - a_5 \quad (5)$$

The initial storage can be estimated by correlating with the long-term average discharge volumes. As an initial estimate,

$$S_i = 2 \bar{S} \quad (6)$$

Data Gathered

The water balance model used climatic data and streamflow record. The data were obtained from Philippine Atmospheric Geophysical and Services Administration in Quezon City and local stations in the field; National Irrigation Administration in the Quezon City and Lucena City; Department of Agriculture; National Mapping and Resource Information Authority, and Organization for Industrial, Spiritual and Cultural Advancement Center in Lucban, Quezon. The potential evapotranspiration from the watersheds was computed using the Penman-Monteith method (Smith, 1993).

Parameters of the Model and Optimization Process

Estimation of values of the five parameters was determined by optimization process. The initial values used were the values used by Van Der Beken and Byloos (Singh, 1988 and Siti, 1995) as presented in Table 1. The first output of the computer program was compared to the monthly observed streamflow of the watershed for the same year. Further, in the optimization process, one step higher and one step lower was made to every value of the parameter as seen in Table 1. The new values were substituted one-by-one to the value of parameter as input to the computer program. The initial process done is to determine the trend of the predicted streamflow as compared to the observed streamflow.

Table 1. Initial Values of Parameter of Model for Optimization Process.

Parameters	Value of para-one step lower than standard value	Standard value	Value of para-one step higher than standard value
a_1 (Soil Texture)	0.005	0.01	0.02
a_2 (Soil Texture)	0.170	0.27	0.37
a_3 (Degree of Urban.)	0.100	0.20	0.30
a_4 (Percolation)	0.020	0.03	0.04
a_5 (Canal Loss)	2.000	3.00	4.00

The trend gave direction whether to increase or decrease the value of the parameter and to select the parameters that has strong influence of the desired results. In this research the observed and predicted streamflow are governed by the following criteria to finish the iteration:

1. Highest value of coefficient of correlation is obtained from the observed and predicted streamflow.
2. The correlation coefficient is significant at 0.05 level.
3. The difference between the mean of the observed and predicted streamflow is not significant.
4. Smallest value of percent error is obtained, and
5. Sensitivity test is giving almost similar value but opposite in sign.

The final value of the parameter was selected after adding and subtracting smaller amount to the parameter determined earlier. A minimum of 33 iteration is required to finish the determination of parameters.

RESULTS AND DISCUSSION

Watershed Parameters Used in the Model

The values of model parameters (Table 2) determined by optimization produced the predicted monthly streamflow of *Janagdong* River Watershed near the observed monthly streamflow of the watershed from 1984 to 1986. Higher values for parameter a1 and a2 were noted as compared to the standard values mentioned in Table 1 due to the presence of sandy soil texture of the *Janagdong* River Watershed. This is

parameter a2 will increase if the soil texture becomes sandy. The value of parameter a3 is lower than the values established by Van Der Beken and Byloos (Singh, 1989). This is attributed to the low urbanization of the watershed. The existing vegetation and forest cover of the watershed is maintained as evidenced by continuous tree planting activities in the area, prohibition of cutting of trees in the watershed because it is national park and the voluntary evacuation of the occupied land in the watershed by local farmers.

Table 3. Numerical Values of Five Parameters of the Model Determined in *Janagdong* River Watershed from 1984-1986.

Parameters	Numerical Values
a_1	0.09
a_2	0.44
a_3	0.01
a_4	0.03
a_5	2.00

Observed and Simulated Streamflow

The predicted monthly streamflow is following the trend of the observed monthly streamflow in the watershed from 1986-1989 as presented in Figure 1. The two are significantly correlated but the difference of their means is not significant (Table 3). The percent error is 26.04 and the mean volume of streamflow of predicted and observed streamflow is 7,675,113 m³ and 8,179,471 m³, respectively.

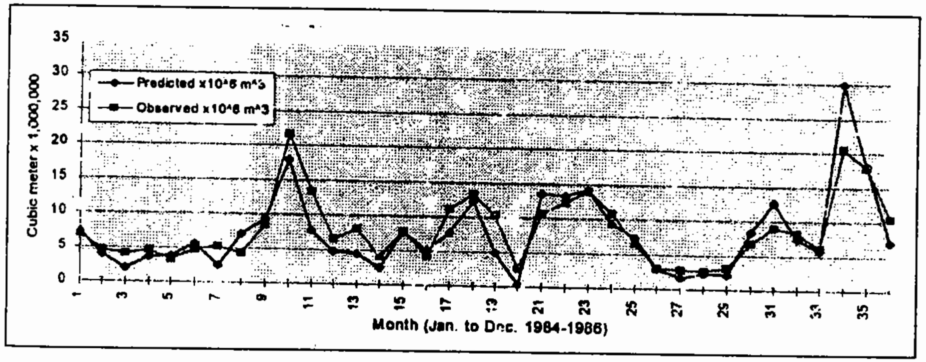

Figure 1. Graph of predicted and observed streamflow of Janagdong River Watershed using a_1, a_2, a_3, a_4 and a_5 parameters form 1984-1986.

Table 3. Monthly Predicted and Observed Streamflow From 1984-1986 in *Janagdong* River Watershed, million cubic meters.

Month	1984 Predicted Streamflow	1984 Observed Streamflow	1985 Predicted Streamflow	1985 Observed Streamflow	1986 Predicted Streamflow	1986 Observed Streamflow
Jan	7.28172782	6.82992	4.4249177	8.115552	7.37405818	6.508512
Feb	3.9062383	4.620672	2.44253046	4.088448	2.98293465	2.999808
Mar	1.90484188	4.15152	7.66191169	7.660224	1.5816856	2.81232
Apr	3.58851324	4.536	5.08460827	4.30272	2.32304412	2.69568
May	3.80847676	3.348	7.71350808	11.24928	2.16282379	3.160512
Jun	5.61706567	4.7952	12.3626135	13.37472	8.32723344	6.71328
Jul	2.50227366	5.22288	4.91100994	10.31184	12.5852926	9.1065
Aug	7.12150750	4.312224	0.2781981	2.598048	7.33060862	8.222688
Sep	9.28583987	8.39808	13.4950183	10.60128	5.67409325	6.03936
Oct	17.9648942	21.721824	13.2370364	12.267072	30.0710344	20.48976
Nov	7.77053564	13.27104	14.1929272	13.97088	18.0137749	17.98848
Dec	4.77522997	6.562080	9.41347301	10.901088	7.13236987	10.499328
Total	75.52714451	87.76944	95.2177527	109.441152	105.5589534	97.236228
Mean	6.293928709	7.31412	7.93481272	9.120096	8.796579452	8.103019

Test of correlation:

df = 34
r comp. = 0.888
r tab (0.01) = 0.424

Test of the difference between mean:

df = 35
t comp = 1.106
t tab(0.01) = 2.032

Validation of the Model

Validation of the model was done in the same watershed from 1987 to 1989. The same model parameters were used with the assumptions that there were no changes in the condition of the watershed as to vegetation and surface cover. Likewise, the moisture storage in the soil is assumed the same as that of the previous years. These assumptions are supported by the fact that the watershed is planted with permanent crop such as coconut and fruit trees on the lower portion and permanent forest on the upper portion of the watershed.

***Janagdong* River Watershed.** The 5 parameters of the water balance model are valid to use in the watershed. The monthly predicted and observed streamflow are following the same trend for the three year-period of study. There is significant correlation between the predicted

predicted streamflow and vice versa. The parameters a_3 and a_5 is also sensitive but to a lesser degree. The trend is in the opposite direction. An increase of the value of parameter produced a decrease in the predicted streamflow and a decrease in the value of parameters resulted to an increase in the predicted streamflow.

Table 6. Effect of Changing the Parameters 1_1 to a_5 with Respect to Standard Predicted Streamflow for *Janagdong* and *Dumacaa* River Watersheds.

Parameter	Percent change to parameters	Percent difference JRW 1987	JRW 1988	JRW 1989	JRW 1999
a_1	5	0	0	0	-1.73
	5	0	0	0	1.92
	10	0	0	0	-3.30
	10	0	0	0	4.04
a_2	5	3.45	3.41	3.41	3.75
	5	-3.56	-3.52	-3.51	-3.86
	10	6.80	6.73	6.71	7.41
	10	-7.23	-7.15	-7.13	-7.82
a_3	5	-0.03	0.01	0.01	-0.12
	5	0.03	-0.01	-0.01	0.15
	10	-0.07	0.01	0.03	-0.31
	10	0.07	-0.01	-0.03	0.31
a_4	5	-0.20	-0.15	-0.13	-0.17
	5	0.20	0.15	0.13	0.17
	10	-0.40	-0.29	-0.03	-0.33
	10	0.40	0.29	0.26	0.33
a_5	5	0.07	0.05	0.04	0.06
	5	-0.07	-0.05	-0.04	-0.06
	10	0.13	0.10	0.09	0.12
	10	-0.13	-0.10	-0.09	-0.12

For *Dumacaa* River Watershed the a_2 (parameter related to soil texture) is the most sensitive to changes made like in *Janadong* River streamflow. On the contrary a decrease of 5% to the parameter resulted to a decrease on the streamflow of 3.856%. The a_5 parameter is the least sensitive to changes made. The parameter a_1 is the second most sensitive. A change of +5% resulted to a decrease of 1.73% on the volume of streamflow and a decrease of 5% produced an increase of 1.91% on the streamflow. The parameter a_4 and a_5 produced minimal change. The percent change is presented in Table 6 above.

CONCLUSION

The result of the study leads to formulate the following conclusions:

1. The parameters of the model to determine the monthly streamflow of *Janagdong* River Watershed are a_1=0.09; a_2=0.44; a_3=0.01; a_4=0.03; a_5=2.00 and the value of a_1=0.01; a_2=0.37; a_3=0.20; a_4=0.03; a_5=2.10 are the value of parameters for *Dumacaa* River Watershed.
2. The monthly streamflow of *Janagdong* River Watershed can be estimated using the monthly precipitation and monthly potential evapotranspiration recorded from the nearest hydrometeorological stations using the Van Der Beeken and Byloos water balance model. For *Dumacaa* River Watershed, the streamflow can be predicted but further research is necessary to validate the result.

REFERENCE

Anonymous. 1995. *Region 4 Janagdong River Irrigation System Improvement Component II OSP National Irrigation Administration*, Quezon City, Philippines.

Anonymous. 1998. *Tropical Cyclone Summary, Philippine Atmospheric, Geophysical and Service Administration*, Quezon City, Philippines.

Bear, Jacob. 1979. *Hydraulic of Groundwater*. McGraw-Hill Inc. Israel.

Biswas, Asit K. (Editor). 1976. *System Approach to Water Management*. McGraw-Hill Kogakusha, Ltd., Tokyo.

Bonell, Michael, Maynard M. Hufschmidt and John S. Gladwell. 1993. *Hydrology and Water Management in the Humid Tropics*. Cambridge University Press, New York.

Brdys, M. A. and B. Ulanicki. 1994. *Operational Control of Water Systems: Structures, Algorithms and Applications*. Prentice Hall International (UK) Ltd., New York.

Lal, R. and E. W. Russel. 1981. *Tropical Agricultural Hydrology Watershed Management and Land Use*. John Wiley and Sons, New York.

Linsley, Ray K. and Joseph B. Franzini, David L.Freyberg and George Tchobanoglous. 1992. *Water-Resource Engineering*, McGraw-Hill International Editions, New York.

Linsley, Ray K. and Joseph B. Franzini. 1979. *Water Resources Engineering*, McGraw-Hill Inc., Tokyo, Japan.

Linsley, Jr. Ray K., Max A. Kohler and Joseph L. H. Paulhus. 1988. *Hydrology for Engineers*. McGraw-Hill Book Company, London.

Lukman Hidayat, Putu Sudira and Sahid Susanto. 1996. Model Hidrologi Produksi Air Bulanan Bagian I: Kalibrasi dan Analisis Kepekaan. *Agritech Majalah Ilmu dan Teknologi Pertanian* Volume 16 No.3.

Lukman Hidayat, Putu Sudira and Sahid Susanto. 1996. "Model Hidrologi Produksi Air Bulanan Bagian II: Analisis Korelasi Antara Parameter Model dan Karakteristik Das." *Agritech Majalah Ilmu dan Teknologi Pertanian* Volume 16 No.2.

Mather, John R. 1974. Climatology: *Fundamentals and Applications*. McGrawHill Book Company, New York.

Navasero, Cecilia S. 1993. Upland Farming System in Lucban, Quezon and Itís Ecological Implication in the Conservation and Management of Mount Banahaw de Lucban, Watershed. (Unpublished *Masteral Thesis*) University of the Philippines, Los Banos, Laguna, Philippines.

Nam, K, R. Phien and I. Gupta. 1995. *A Textbook of Engineering Meteorology*. Dhampat Rai & Sons, New Delhi.

Oblefias, Dan. 1998. *Profile of the River System of Lucban*, Quezon (Unpublished). Office of the Municipal Planning and Development Coordinator, Lucban, Quezon, Philippines.

Putu Sudira. 1989. "Runoff Prediction Model Based on Soil Moisture Analysis.: Unpublished *Dissertation*, University of the Philippines, Los Banos, Laguna, Philippines.

Raghunath, H. M. 1987. *Ground Water*. Second Edition. Wiley Eastern Limited, New Delhi, India.

Roberts, Nancy, David F. Andersen, Ralph M. Deal, Michael S. Garet and William A Shaffer. 1983. *Introduction of Computer Simulation: The system Dynamics Approach*. Addison-Wiley Publishing Company, Massachusetts.

Sahid Susanto and Yoshiro Kaida. 1991. "Tropical Hydrology Simulation Model 1 for Watershed Management." *J. Japan Soc. Hydrology and Water Resources*. Vol.4 No. 2 43-53.

Singh, Vijay P. 1988. *Hydrologic Systems Volume I Rainfall-Runoff Modeling*. Prentice Hall, Englewood Cliffs, New Jersey.

Singh, Vijay P. 1989. *Hydrologic Systems Volume II Watershed Modeling*. Prentice Hall, Englewood Cliffs, New Jersey.